TS-84-01

Applications for Microelectronics in Highway Engineering, Operations and Maintenance Processes

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Abstract:

A study to identify potential applications of microelectronic process control technology in highway construction, operations and maintenance identified and evaluated 34 initial candidates. Of these, a number of implementations were already underway. Of the remainder, only two promising new applications were identified for further study. These are hand-held recorders and road/weather information systems. The concept of a road/weather information management centre to improve the cost-effectiveness of winter highway maintenance operations is developed, and an implementation plan for a proposed demonstration project is outlined.

Key Words: winter highway maintenance, weather information system, microelectronics

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Applications for Microelectronics in Highway Engineering, Operations and Maintenance Processes

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STATEMENT OF PURPOSE

In January 1981, the Ontario Ministry of Transportation and Communications commissioned HSW Controls, a Division of Howard S. White Ltd. of Toronto, to investigate the potential applications of process control technology to the Ministry's highway construction and maintenance operations.*

The first phase of the investigation started with an extensive review of the Ministry's reported needs and of developments which are taking place elsewhere; this led to the recommendation of a shortlist of more promising applications for further examination. These applications were:

- highway weather sensing devices,
- laser and other techniques of layout and design surveying,
- hand-held highway condition recorders.

The investigations and evaluations leading to these recommendations were documented in an interim working paper which was submitted to the Ministry on May 22, 1981. Subsequent consideration of these recommendations and certain other possibilities led to a decision to focus the second phase of the project on the collation of additional information regarding weather sensing and hand-held recorders.

This report summarizes the findings made during the second phase of the project and puts forward recommendations and a plan of action.

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*The terms of reference specifically excluded traffic control systems and management, financial and office information system, as well as computer based applications such as computer-aided design techniques.

EXECUTIVE SUMMARY

This study was undertaken to identify potential applications within the Ministry of new microelectronics-based process control technology in the areas of highway construction, operations and maintenance. The study was carried out in two phases.

Phase I was an extensive review of potential applications in the light of Ministry needs. From this review, two applications were selected as having the greatest promise. These applications were:

- highway weather sensing devices,
- hand-held highway condition recorders.

Phase II of the project (which is the subject of this report) involved detailed evaluation of the applications selected in Phase I. The results of the Phase II evaluation are as follows.

Highway Weather Sensing Devices -- Recent developments in technology for monitoring weather conditions hold out the prospect of improving the effectiveness of short-term weather forecasts for road maintenance during winter months by strengthening and centrally integrating MTC's current information base. Improved forecasts are expected to provide the opportunity for significant improvements in the efficiency of plowing, sanding and salting activities with attendant financial and social benefits.

To facilitate this, the report proposes development of a Transportation Nerve Centre (TRANCEN) which would serve as a weather information management centre for much of Southern Ontario. An initial demonstration project covering a carefully selected area would cost less than 1% of the current winter maintenance budget and would likely yield winter maintenance cost savings well in excess of demonstration costs. In recent years, MTC has successfully contained expenditures on winter maintenance in current dollars. The development of improved procedures for anticipating and monitoring weather conditions could enable the Ministry to maintain this enviable position for a further period of time.

Hand-Held Highway Condition Recorders -- A number of systems have been developed to facilitate the electronic recording and analysis of field observations. Field observations are keyed directly into the memory of pre-programmed hand-held recorders. Stored information is then transferred directly to a mainframe computer for analysis and interpretation using, if necessary, a telephone coupler.

Such systems reduce the possibility for errors in the initial recording of data and eliminate sources of error in the collection, transcription and entry of survey data. The systems are equally applicable to a wide range of data collection and analysis needs.

They can also be custom-programmed for special applications. Typical systems, including estimated costs, are reviewed and summarized in tabular form.

AUTHORSHIP

The study was undertaken by Dr Howard White and Gary Moore of HSW Controls, a Division of Howard S. White Ltd., with the advice and participation of Brian Helm of B. Helm Associates Ltd., without whose help some of the concepts developed here would not have been possible.

ACKNOWLEDGEMENTS

The team wishes to thank the members of the Steering Committee (Messrs. J.H. Blaine, D.R. Brohm, Z.T. Byblow, J.T. Kernaghan, R.P. Northwood and G.M. Sinclair) who have greatly helped us in the work. We would especially like to thank the Committee's Chairman, Mr E.R. Case, and the Project Leader, Mr E. Schroeder of Research and Development Branch, for their advice and guidance.

1/ THE SHORTLISTING OF SELECTED APPLICATIONS

During the first phase of the project, an extensive review was made of the potential applications of process control to the MTC's highway construction and maintenance operations. An evaluation of these potential applications led to a shortlisting of those which appeared to be the most appropriate to the MTC. The findings of this first phase in the review of process controls were documented in an interim working paper submitted to the Ministry on May 22, 1981. The following paragraphs provide a summary of that first phase report.

1.1/ Approach

The review of potential applications for process control was undertaken in two stages. In the first stage, a long list of possible applications was developed through a search of published literature and through discussions with representatives of the MTC and a number of other agencies involved in the research and development of highway construction and maintenance systems in Europe. In the second stage, a preliminary evaluation was made of the likely value of each potential application of process control to the current work of MTC. A shortlist of the most promising candidate applications was put forward for consideration by MTC.

1.2/ The Long List

An extensive computerized search was made of several databanks to identify candidate applications of process control. This search was supplemented by information included in papers given at conferences held by the Institution of Highway Engineers and Civil Engineers in London, England during the early part of 1981.

Further information on possible applications was obtained through interviews with senior MTC personnel and with representatives of research laboratories in England, France, and The Netherlands. Appendix A is a summary of the interviews conducted.

A convenient format was developed to summarize the key information regarding each of the candidate applications identified in this review of

developments in process controls. An example of the format is shown in Figure 1. The application summaries are on file with the MTC Research and Development Branch and with the Steering Committee members.

A total of 43 developments was documented. This long list of candidate applications is believed to include most of the recent developments in process control for highway engineering and maintenance operations; nevertheless, with the rapid developments which are currently taking place in the "high-tech" field, it is likely that other potential applications will be developed in the months ahead; the summary format and evaluation procedures developed by this project should enable each application to be recorded and assessed on a continuing basis.

1.3/ Criteria for Selection

Based on an initial discussion with representatives of the MTC, certain of the candidate operations were dropped from further consideration. These included applications for which there would be very limited use (such as toll facilities) and certain others which MTC has already adopted (such as a new skid trailer with micro-electronic functions and sensors for monitoring vibrations on structures). In all, 34 developments were taken forward for further examination*. For convenience, the residual long list of candidate applications was divided into those which are directly under MTC control (such as weather monitoring and lane marking) and those over which MTC has only indirect control (such as paving activities which are subcontracted).

Each candidate application was evaluated in terms of the extent to which it satisfied a set of key criteria including:

- whether or not the new application addressed a problem or a deficiency which had been identified by the Ministry;

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* The classification of the potential applications is tabulated in Appendix B.

Figure 1/ MTC's Applications of Process Control in Highway Engineering and Maintenance -- Review of Developments

ACTIVITY: Highway Operations -- Weather Condition Sensing	CODE: 001
APPLICATION: Automatic Remote Sensing of Highway Weather Conditions	

SOURCE: Automatic Weather Station with Speech Output; Freden S; Natl Swedish Road Admin, 1979 Monograph, 18 p. Automatic Fog Alert System Protects Busy Highway; Rural and Urban Roads, VII, N5, May 1973, p. 36

DESCRIPTION:

KEY FEATURES: Use of remote sensors to detect weather conditions including fog at various points in a highway network.

Swedish system developed to warn of extreme skidding risks. Automatically records meteorological data of special relevance and reports condition data verbally over telephones. Two US systems detect reduced visibility due to fog conditions. One system activates warning lights while the other controls lighting intensity. Sensors can detect other conditions such as snow.

SOURCE (cont'd): Automatically Speaking Weather Station; Gilen C; Natl. Swedish Road and Traffic Research Institute, 1978 Monograph, 101 p. Installation of Fog Guidance Lights on Afton Mountain, Virginia Highway and Transportation Research Council, Aug. 1976, 58 p.

ALSO CROSS-REFER TO:

008

SIMILAR PROCESSES:

Various types of remote sensing devices which collect and transmit predetermined data sets.

STRENGTHS AND WEAKNESSES:

FAVOURABLE:
Automatic control of warning signs and/or lighting systems during hazardous highway conditions. Swedish and US systems are tested and operational.

UNFAVOURABLE:

OTHER CONSIDERATIONS:

POTENTIAL FOR MTC:

NOT APPLICABLE		SIMILAR PROCESSES ALREADY IN USE BY MTC	
APPLICATIONS LIKELY	X	RAISED DURING MTC INTERVIEWS	X

STEERING COMMITTEE DECISION:

- whether or not the application was currently under development or operation at the Ministry;

- cost/benefit considerations, such as an identified potential for saving, the requirement for additional R & D investment, purchase price and life expectancy;

- the extent to which the development has been proven experimentally and/or operationally;

- risk factors such as likely acceptability by operatives, technical obsolescence, and suitability for Ontario climate;

- factors such as improved safety, labour savings, improved precision/quality control, reduced energy consumption, improved work capacity, reduced environmental impact, improved reliability, simpler operation, and multiple applications.

A scoring system was developed to assist in evaluating the relative impact of each development. This scoring system was used strictly as an aid to evaluating the relative merits of the candidate applications, and a series of sensitivity tests were used to determine the stability of the resulting ranking to different weightings of the significance of the various criteria.

The results of this evaluation are shown in Tables 1 and 2. The scores shown at the foot of the two exhibits give equal weight to each criterion. The criteria scores are coded as follows:

2 = application offers substantial benefit
1 = application offers some benefit
0 = application offers no apparent benefit
# = application may run into some difficulty
? = information not readily available
* = information not available during phase 1

Because of the inherent risks in attempting to rank alternatives through the aggregation of scores applied to criteria which are not directly

Table 1/ Evaluation of Potential Applications

APPLICATIONS DIRECTLY CONTROLLED BY MTC

Note: (--) Technologies in use or currently under development by MTC were not evaluated.

Criteria / Code	C03 Shoulders	C04 Lasers	C05 Inertial	C06 EDM	C13 Gamma	001/008 Weather	002 Road	003 Remotelite	010 Centlite	004/006/007 Scales	005 V. Class	009 Roadside	011/C12 Lane Mark	M01/M05 Photolog	M02 Robot	M03/M04 Hand-Held	M08(M06/M07) Profile	M09 Load Cell
MTC identified problem or deficiency with existing method	No	Yes	No	No	In Use	Yes	In Use	Yes	Yes	In Use	Yes	No	In Use	In Use?	Yes	Yes	No	No
Currently under development/ operation at MTC	No	No	No	No	Yes	No	Yes	No	No	Yes	No	No	Yes	Yes?	--	No	No	No
Cost/benefit appraisal																		
• Cost of current operation	?	?	?	?	--	?	--	?	?	--	?	Nil	--	--		?	?	Nil
• Potential saving	?	50% Labor	?	Yes	--	Yes	--	?	?	--	?	Vandals	--	--		Yes	?	Nil
• Required Investment																		
- Additional R & D	?	No	Yes	No	--	Yes	--	No	Yes	--	?	Yes	--	--		Limited	Limited	Yes
- Purchase price	?	?*	?	?*	--	?*	--	?*	?	--	?	?	--	--		Minimal*	?*	?*
- Life Expectancy	?	?*	?	?*	--	?*	--	?*	?	--	?	?	--	--		?*	?*	?
Development proven:																		
• Experimentally	--	--	Yes	--	--	--	Yes	--	Yes	--	Yes	Yes	--	--		--	Yes	Yes
• Operationally	Yes	Yes	--	Yes	Yes	Yes	--	Yes	--	Yes	---	?	Yes	Yes		Yes	?	--
Risk factors																		
• Acceptability by operatives	#	0	0	0	--	0	--	0	0	--	0	0	--	--		0	0	0
• Technical obsolescence	0	0	0	0	--	0	--	0	0	--	0	0	--	--		0	0	0
• Climatic stamina	0	0	0	0	--	0	--	0	0	--	0	0	--	--		0	0	?
Development offers:																		
• Improved safety	1	0	0	0	--	2	--	2	2	--	0	1	--	--		0	0	0
• Labour saving	0	2	2	2	--	2	--	0	1	--	2	1	--	--		1	0	1
• Improved precision/quality control	0	2	2	2	--	2	--	1	2	--	2	0	--	--		1	2	2
• Reduced energy consumption	0	0	0	0	--	1	--	1	1	--	0	0	--	--		0	0	0
• Improved work capacity	1	2	1	2	--	0	--	0	0	--	0	0	--	--		2	1	0
• Reduced environmental impact	0	0	0	0	--	0	--	0	0	--	0	0	--	--		0	0	0
• Improved reliability	0	1	2	1	--	2	--	0	1	--	1	1	--	--		1	1	2
• Simpler operation	0	2	0	1	--	2	--	0	1	--	2	0	--	--		2	0	0
• Multiple uses	2	0	0	0	--	2	--	0	0	--	0	0	--	--		2	0	2
Score	4	9	7	8		13		4	8		7	3				9	4	7

— USE NOT CLEAR —

Table 2/ Evaluation of Potential Applications
Applications Indirectly Controlled by MTC

Criteria / Code	C01/C12 Paving	C02 Aggre.	C07 Pile	C08/C11 Recipe	C09 Loops	C10 T Test
MTC identified problem or deficiency with existing method	No	No	No	No	No	No
Currently under development/ operation at MTC	No	No	No	Yes	No	No
Cost/benefit appraisal						
• Cost of current operation	?	?	?	?	Nil	?
• Potential savings	?	?	?	?	Nil	?
• Required Investment						
- Additional R & D	No	Yes	No	No	Yes	Yes
- Purchase price	?	?	?	?	?	?
- Life expectancy	?	?	?	?	?	?
Development proven:						
• Experimentally	-	Yes	-	Yes	Yes	Yes
• Operationally	Yes	?	Yes	?	?	?
Risk factors						
• Acceptability by operatives	0	0	0	0	0	Lab
• Technical obsolescence	0	0	0	0	0	0
• Climatic stamina	0	0	0	0	?	0
Development offers:						
• Improved safety	0	0	0	0	0	1
• Labour savings	1	0	2	0	0	0
• Improved precision/quality control	2	2	2	2	2	2
• Reduced energy consumption	1	0	0	0	0	0
• Improved work capacity	2	2	2	2	1	0
• Reduced environmental impact	0	0	0	0	0	0
• Improved reliability	2	2	2	2	2	2
• Simpler operation	?	?	2	0	1	0
• Multiple uses	0	0	0	0	2	0
Score	8	6	10	6	8	5

comparable one with another, a second qualitative evaluation was made of the significant merits offered by each application. This evaluation of merit focused on:

- safety improvements,
- labour savings,
- quality improvements,
- energy savings.

The procedure used is summarized in Figure 2.* This qualitative approach included the screening of promising applications from the perspective of current or anticipated MTC development and sidetracked those applications which could represent a duplication of effort.

1.4/ The Shortlist

The results of the two evaluation procedures were compared. On the strength of that comparison, the following applications were considered to warrant further investigation:

- the automatic remote sensing of highway condition which promises to offer opportunities to reduce expenditures significantly on ice and snow removal and yet, at the same time, enhance public safety;

- hand-held recorders which appear to offer significant opportunities to improve the productivity and accuracy of highway inspection;

- lasers and other advanced survey techniques which appear to offer significant advantages in terms of reduced costs and improved accuracy.

1.5/ Review by Steering Committee

Following a review of the interim report on the findings of the first phase, the Steering Committee endorsed the recommendation to proceed with

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* Note: The application codes and labels in this figure and in the preceding tables are tabulated in Appendix B.

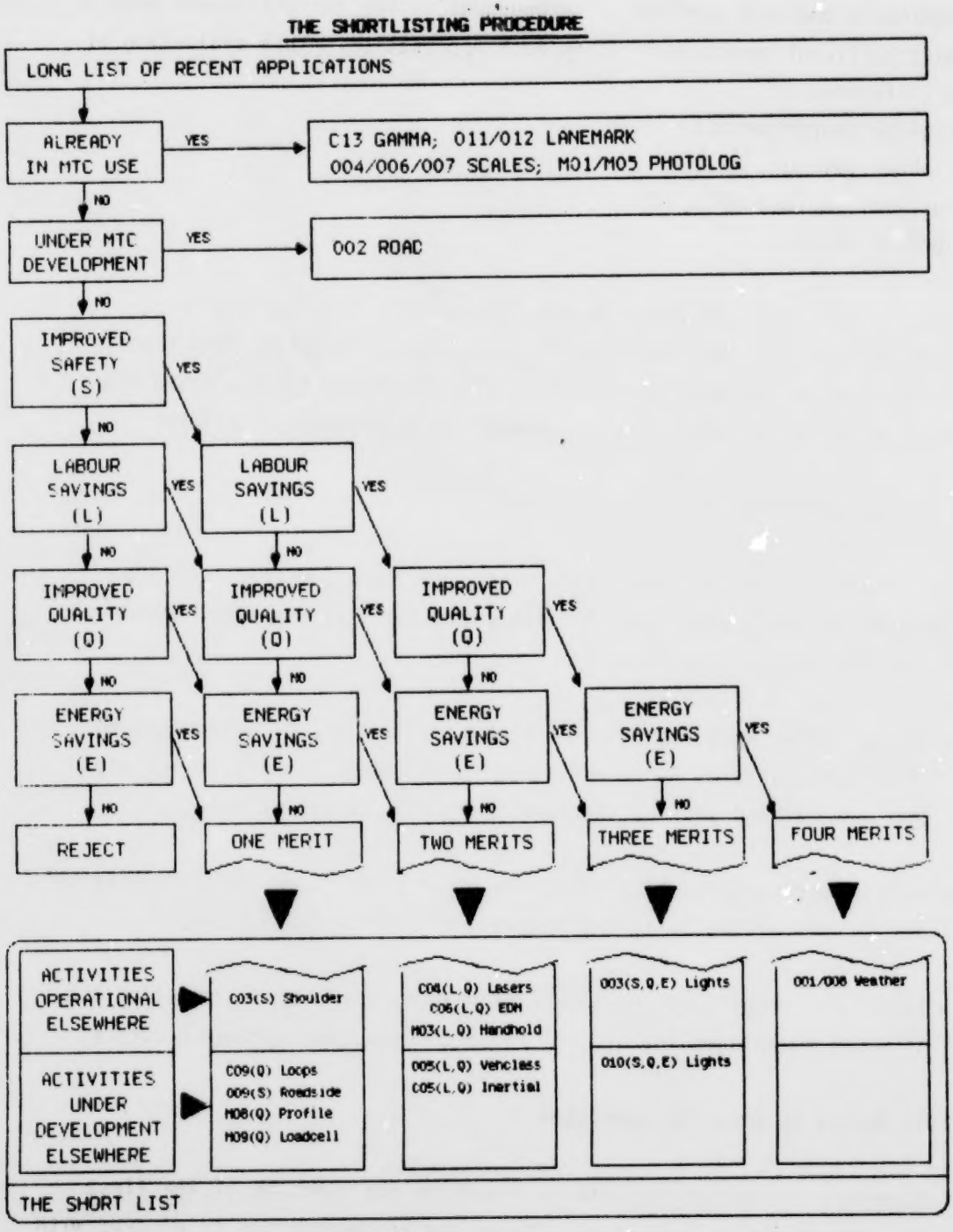

Figure 2/ MTC's Application of Process Control in Highway Engineering and Maintenance -- the Shortlisting Procedure

further investigations into remote weather sensing and with the collection of additional information on hand-held recorders. It was, however, agreed that MTC would itself proceed with further investigations into advanced survey techniques.

This decision was confirmed in a letter dated February 1982 requesting HSW Controls to proceed with the second phase of the project.

2/ WEATHER MONITORING

The remote sensing of highway weather conditions appears to offer the opportunity for substantial saving in the costs of keeping highways passable during winter months. To see just how significant this could be, it was decided to take a broad look at the way in which weather conditions are monitored at the present time. This led to an examination of scope for improvement, including the best way of capitalizing on recent developments in microprocessing. This section of the report summarizes the findings of these investigations into weather monitoring and concludes with recommendations for a demonstration project to evaluate the benefits of establishing a Transportation Nerve Centre for the direction of winter road maintenance activities.

2.1/ Minimizing the Hazards of Winter

2.1.1/ Principal Problems

The main problem facing those responsible for keeping Ontario's highways open and safe for traffic during winter months lies in anticipating the onset and intensity of adverse weather conditions. Improvements in the reliability of forecasting inclement weather would enable MTC to cut down on the mobile resources which are held on active standby and to achieve a tighter control on the frequency and quantity of sanding and salting operations.

Once the weather has turned inclement, there is also the problem of monitoring the surface condition, especially with regard to icing. Reliable indications of the absence of ice would enable a tighter control to be exercised over the spreading of sand and salt.

During snow storms and periods of high wind, there is also the problem of visibility. Improved methods for detecting "white-outs" would enable advance warnings to be given to drivers and, if necessary, road closures implemented. To a lesser extent in Ontario, the same problem exists with fog.

Overall, an improved ability to anticipate and monitor prevailing weather conditions would offer the opportunity for significant saving in road maintenance costs during winter months and enhance the safety of the driving public. (In 1981/82, well over $40 million was spent on winter maintenance.)

2.1.2/ Legal Obligations

In recent years, the courts have upheld claims against the Ministry based on failure to maintain the King's Highways in accordance with internal maintenance quality standards (see Landriault vs the Queen, and Cote vs the Queen in 1977). It therefore appears that there is an onus on the Ministry to maintain the highways in an open and safe condition during the winter months.

There is, of course, an obligation placed on drivers of road vehicles to proceed with due care and attention, particularly during the winter months.

2.1.3/ Ministry Targets

MTC's manual on maintenance quality standards (M-700-1) calls for all Class 1 roads with a winter-time ADT* of over 2000 to be plowed bare within 24 hours of the end of a snowfall. This same standard requires that the depth of snow should not be allowed to exceed 2.5 cm. These requirements apply to some 80-90% of the King's Highways in Southern Ontario.

2.1.4/ Current Operating Practices

Snowplows and sand and salting equipment operate from approximately 300 patrol yards which, in Southern Ontario, are some 30 to 50 km (20 to 30 miles) apart. For administrative purposes, the patrol yards are grouped into 18 districts. The primary responsibility for keeping a watch on the weather rests with the road inspectors at each patrol yard. Experienced judgement of weather conditions is supplemented by official weather forecasts, including a forecast four times a day from Environment Canada's service at Toronto airport.

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*Average Daily Traffic

The onset of storms is tracked by radio communication between patrolmen. This means that with the majority of prevailing storms approaching from the west, inland patrol yards get some advance warning.

The prevailing condition of the highways is assessed by inspection once or twice a day in rural areas and two to three times a day in urban areas. These inspections are carried out on a regular basis by patrolmen who, in addition to monitoring surface conditions, are also looking for marooned vehicles. Supplementary reports are also received from equipment operators.*

Once the inclement weather arrives, plows and sanding/salting equipment are dispatched from the patrol yards in response to instructions from mobile patrolmen. The rates of plowing and sanding/salting are left to the discretion of patrolmen.

Currently, there is no clear cut definition of what constitutes an appropriate mix of salt and sand; practices vary from district to district. Most commonly, about 5% of salt is added, but in Toronto and Hamilton 15% is the norm and in Ottawa the usual recipe is pure salt. MTC has been conducting a study to determine the most appropriate mix under a range of road and weather conditions.** However, in the absence of reliable information regarding surface conditions, it will still be difficult to apply the findings.

A salting/sanding procedure that has been suggested is to wait until 3/4 of a centimetre of snow has fallen and then to lay sand or salt at frequent intervals until the storm is over. However, the lack of advance

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*Reports on road conditions in each of the districts are transmitted by CN/CP teletype to all districts and to Downsview where they are combined with Environment Canada short and 12-hour forecasts of weather conditions for 15 selected airports throughout the province (deciphered and correlated to districts by MTC staff) to produce a regularly updated summary for MTC's phone-in Road Information Service.

**Harold Fromm has recently completed a study of the optimum mix of salt and sand for a range of road conditions, "Winter Maintenance Study for Reduced Salt Usage" MTC report MSP-82-02. See also, "Sprinkle Lightly -- Salt and Alternatives for Highway De-icing," MTC report MSP-84-01.

warning and practical limits on the availability of equipment often preclude this procedure.

Area patrol supervisors are responsible for co-ordinating patrol yard activity within their area. However, these supervisors are not currently equipped to co-ordinate and interpret weather reports on a formal basis. Thus, each yard is left to do its best.

2.1.5/ Current Expenditures

Table 3 summarizes the direct costs of road maintenance during the past three winters. The figures have been abstracted from Ministry records of the direct and contracted costs of winter maintenance. For comparison purposes, the data are presented in units of expenditure (e.g., person hours).

In the 1981/82 period, the total recorded expenditure on road maintenance was $41.1 million (up to the 5th of March). The make-up of this expenditure was as follows:

• administration (including $3.2 million for road patrols)	$ 5.0 million
• plowing	9.2 million
• sanding (including $1.8 million for sand)	8.3 million
• salting (including $5.5 million for salt)	14.2 million
• MTC personnel on active standby	4.4 million
TOTAL	$41.1 million

An examination of the expenditure levels during the past three years indicates that:

- administrative costs appear to be declining, led by a cutback in road patrols;
- there has been a substantial cutback in the personnel held on active standby;
- almost all of the equipment used for sanding and salting is hired on contract;
- the bulk of plowing is done by MTC equipment, though the trend to increase contracting with private operators is clearly discernible.

Table 3/ The Consumption of Resources by Winter Maintenance (Abstract of Information Provided by MTC)

ITEM	UNIT	1979/80	1980/81	1981/82 (Up to 82/03/05)	1981/82 Expenditure
ADMINISTRATION					
- Road Patrol	Person h	355 577	Records	229 519	($3.2 million)
	km	11.8 million	Incomplete	7.9 million	
Total Admin.	Person h	600 044		410 842	$5.0 million
PLOW					
-MTC Staff	Person h	302 836	370 767	345 855)	
-All Equipment	h	168 213	208 024	207 261)	$9.2 million
	km	4.6 million	5.8 million	5.7 million	
	(% private)	(3.5%)	(6.0%)	(10.4%)	
SAND					
-MTC Staff	Person h	15 693	17 718	12 879)	
-All Equipment	h	248 044	279 560	221 304)	$6.5 million
	m^3	0.42 million	0.50 million	0.39 million	$1.8 million*
	(% private)	(46.3%)	(45.9%)	(45.4%)	
SALT					
-MTC Staff	Person h	12 189	14 690	11 499)	
-All Equipment	h	157 470	189 153	136 572)	$8.7 million
	T	0.24 million	0.29 million	0.22 million	$5.5 million**
	(% private)	(45.7%)	(45.1%)	(45.5%)	
STANDBY					
-MTC Staff	Person h	1 821 042	780 521	446 150	$4.4 million
TOTAL					
-Excl. sand & salt		$33.1 million	$33.4 million	$33.8 million	$33.8 million
-Incl. sand & salt					$41.1 million

*based on $4.50 per m^3
**based on $25.00 per T

Overall, MTC has successfully contained expenditures on winter maintenance in current dollars. The development of improved procedures for anticipating and monitoring weather conditions could enable MTC to maintain this enviable accomplishment for a further period of time.

2.1.6/ Scope for Improved Effectiveness and Efficiency

There appears to be a lot that can be done to improve the effectiveness and efficiency of MTC's winter maintenance program. This is especially true given MTC's commitment to switching as much plowing, sanding and salting as possible to private contractors. Key opportunities include:

- capitalizing on recent developments in weather forecasting and monitoring,
- the co-ordinated monitoring and interpretation of weather and road condition reports,
- providing tighter guidelines for the spreading of sand and salt (taking into account the Fromm findings and recommendations),
- the development of more reliable 24-hour "all-clear" and two-hour "alerts" forecasts to provide a basis for more cost-effective weather-responsive contracts with private operators.

2.1.7/ The Need for a Transportation Nerve Centre (TRANCEN)

The realization of the scope for improved effectiveness and efficiency hinges on the ability to develop an improved understanding of weather conditions and prospects. Investigations carried out in Phase 1 of this study identified a number of recent developments which would aid the monitoring of weather conditions. Meteorologists are also developing improved methods of forecasting the micro weather (see Section 4, References). Combined with existing sources of information on weather and road conditions, including MTC and OPP patrol reports, these developments appear to offer a data base for the development of more reliable local forecasts of weather.

We believe that the interpretation of this data base can best be done centrally, where judgemental skills can be honed and action initiated on a co-ordinated basis.

2.2/ Weather Forecasting

The art of weather forecasting involves the interpretation and extrapolation of a series of observations regarding barometric pressure, temperature, humidity, wind and cloud formation. The availability of satellite observations of changes in cloud formation has materially improved the general reliability of weather forecasts, but there remains a significant degree of unpredictability at the local level.

This has led in recent years to the development of instrumentation to monitor local weather conditions.

2.2.1/ Status Reporting at the Local Level

Recent developments in instrumentation for monitoring weather conditions at the local level include:

- Weather radar which can detect the presence and approximate intensity of precipitation. Such a system is used by CFTO-TV to show the current regional weather pattern. The distance that can be covered by this method depends on the prevailing height of the cloud base; typically in Southern Ontario, the radar can track precipitation up to 80 km (50 miles) away.

- The development of devices to monitor the temperature and moisture of road surfaces. By combining these readings with measurements of air temperature, this instrumentation detects conditions favourable to the formation of ice [4, 5].* It is understood that such a system was

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*Numbers in square brackets denote references listed in Section 4.

installed experimentally in a tunnel in Thorold and on a bridge in Ottawa, but the Ministry was not satisfied with the results; however, experiments at Toronto Airport appear more promising.

- A device to monitor reductions in visibility due to falling and blowing snow. Based on experimental work in the Antarctic, this system has been developed in Wyoming to the point where it can detect white-out conditions [6,7].

When combined with the systematic reporting of observed weather conditions by patrol yards, these developments offer a powerful data base for local weather forecasting. In addition to the observations on temperature, precipitation and wind direction which is currently reported, the patrol yards could also provide information on:

- barometric pressure and humidity,
- the presence of ice as detected by sideways skid measuring equipment attached to snowplows, sanding and salting vehicles.*

2.2.2/ Observation vs Interpretation

The key to weather forecasting lies in the ability to interpret observed trends in weather conditions over time. The interpretation of these trends requires considerable judgement. The advent of microprocessors has made the exercising of this judgement much more manageable. With the emphasis on trends rather than absolute values, certain kinds of instrumentation (such as ice detectors) have assumed a greater value; their ability to measure precisely the current condition being less important than their ability to measure changes over time.

2.2.3/ Twenty-Four-Hour Condition Forecast

Criticism of weather forecasting tends to focus on the failure of forecasts to anticipate change. From the point of view of making economies in road maintenance costs during winter months, it is arguably more

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*A proposal to test for the presence of ice using a sideways slip wheel attached to the front bumper of salt and sanding vehicles and to the rear of plows was put forward during discussions with MTC engineers.

important to be able to predict no change, that is to say that the probability of a storm is zero during the next say 24 hours. Knowing this, it may be possible to avoid the costs of keeping personnel on standby.* Preliminary discussions with meteorologists indicate that it should be possible to make such predictions with reasonable certainty except to the immediate leeward of the Great Lakes where squalls can form unexpectedly.

Accordingly, it seems reasonable to anticipate that by analysing weather trends from MTC's point of view, it should be possible to achieve significant reductions in the need to hold staff on active standby.

2.2.4/ Two-Hour Micro-Weather Forecast

Approximately two hours are needed to mobilize road maintenance crews on call at patrol yards. This, then, represents the desirable level of advance warning of critical changes in weather conditions within a radius of some 15 to 25 km (10 to 15 miles) of each patrol yard. It is on this scale that regional forecasts typically break down as a result of local phenomena which affect the path and severity of weather movements. The attention of researchers has currently turned towards ways of improving local weather forecasts; one such project is the development of a prototype regional observing and forecasting service being undertaken by the National Oceanic and Atmospheric Administration in Colorado [2]. Central to these researches is the development of a vastly improved data base, through the application of microprocessors to process readings from remote sensors and fully automated ground stations. For short term predictions, dependence is being placed on sophisticated extrapolation techniques which are preprogrammed for immediate call-up from a minicomputer.

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*The feasibility of realizing such saving depends on the revised terms which could be negotiated for the hire of temporary personnel and equipment during winter months. Currently, temporary staff are hired on a guaranteed 40 hour per week plus overtime basis; duty rosters are posted 72 hours in advance. Some equipment is hired for a flat rate per day, some for a standby rental per day plus a rate per hour of use.

From a road maintenance point of view, the focus of forecasting would be on the probability of precipitation in the form of freezing rain or snow two hours ahead of its occurrence. There are a number of recent developments which suggest that this can be done with reasonable reliability by applying experienced judgement to the interpretation of all available information, including the re-examination of satellite based data from a local perspective, as well as the use of surface condition data.

2.2.5/ Surface Condition Forecasting

There are a number of recent developments in instrumentation which have facilitated the extrapolation of changes in the weather conditions at the surface to provide advance warning of critical driving conditions. These developments make it possible to anticipate the approach of conditions which are conducive to ice formation, white-outs, fog and water-planing.

2.2.5.1/ Ice Alert

Ice alert systems have been developed both in Europe and in North America. Typically, the systems use a central minicomputer to process measured changes in road temperature, road conductivity, air temperature, and air humidity. Warnings are generated when a combination of trends points towards conditions which experience has shown to be conducive to ice formation. The importance of applying experienced judgement to the interpretation of calculated trends is underscored by experience at Toronto International Airport where two systems are currently being compared. These systems are:

- The Surface Systems Inc. Scan Surveillance System 16. A remote processor unit combines information, from sensors embedded in the pavement, on surface temperature and conductivity with measurements of air temperature, relative humidity and wind speed/direction. Readings are transmitted by radio or land-line to a central processor unit which provides both video and hard copy summaries of trends during the preceding 60 minutes [5]. A typical example of this basic data output is shown in Table 4A. The central processor analyses the previous hour's trends to identify and alert operatives to developing situations which could lead to ice formation. This system was originally developed to detect ice formation on highways.

Table 4A/ Typical Printout from SSI Scan Surveillance System 16

```
**********************************************************************************

  ECHO .. #3                                TIME 11:04          DATE 03/30/82
  SURFACE CONDITIONS:                       ATMOSPHERIC CONDITIONS:

  DRY

  SURFACE TEMPERATURE: DEG.                 AIR TEMPERATURE: DEG.
     PRESENT              10.0                PRESENT                5.0
     5  MIN. AGO                              5  MIN. AGO
     15 MIN. AGO           9.5                15 MIN. AGO            4.5
     60 MIN. AGO           9.5                60 MIN. AGO            5.0

  AUTO PRINT @ 60 MIN.                      WIND DIRECTION/SPEED 151 /   7 MPH
                                            RELATIVE HUMIDITY            82 %
  PRINT ON STATUS CHANGE ACTIVE             COMMAND
----------------------------------------------------------------------------------
  WHISKEY #1          DRY
  CHARLIE #2          DRY
* ECHO .. #3          DRY


                                            TRANSPORT CANADA-TIA SSI/ROMARK LTD

**********************************************************************************

  WHISKEY #1                                TIME 11:05          DATE 03/30/82
  SURFACE CONDITIONS:                       ATMOSPHERIC CONDITIONS:

  DRY

  SURFACE TEMPERATURE: DEG.                 AIR TEMPERATURE: DEG.
     PRESENT              10.0                PRESENT                5.0
     5  MIN. AGO                              5  MIN. AGO
     15 MIN. AGO           9.0                15 MIN. AGO            4.5
     60 MIN. AGO           9.0                60 MIN. AGO            5.0

  AUTO PRINT @ 60 MIN.                      WIND DIRECTION/SPEED 147 /   7 MPH
                                            RELATIVE HUMIDITY            82 %
  PRINT ON STATUS CHANGE ACTIVE             COMMAND
----------------------------------------------------------------------------------
* WHISKEY #1          DRY
  CHARLIE #2          DRY
  ECHO .. #3          DRY


                                            TRANSPORT CANADA-TIA SSI/ROMARK LTD
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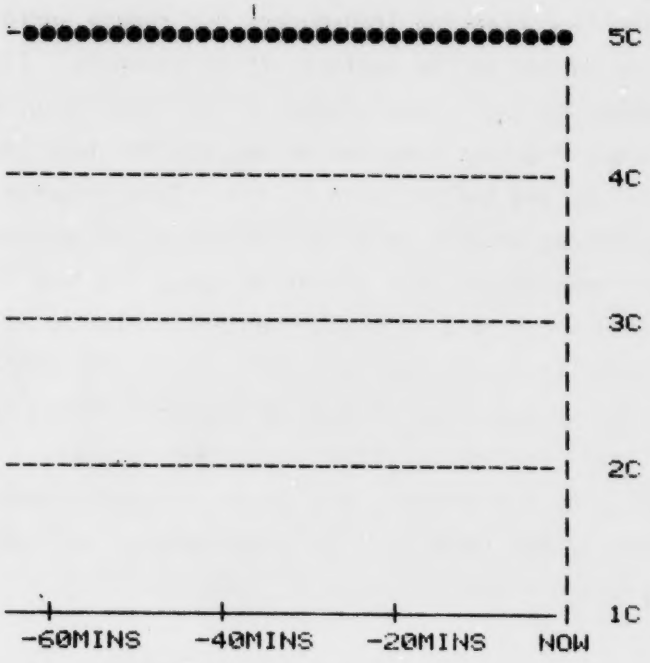
Table 4B/ Typical Printout from Findlay Irvine ICELERT--Mark IV System



11:56 HRS 30/03/82 PAGE 04

GROUND TEMP ON BRAVO

MINS AGO	ECHO		CHARLIE		BRAVO	
	GRND	AIR	GRND	AIR	GRND	AIR
NOW	> 5	> 5	> 5	> 5	> 5	5.8
5	> 5	5.2	> 5	5.2	> 5	6.0
15	> 5	5.4	> 5	5.4	> 5	6.6
30	> 5	> 5	> 5	> 5	> 5	20.0
60	> 5	> 5	> 5	> 5	> 5	5.8

ALL TEMPS IN CENT.

ICELERT REPORT

TORONTO INTERNATIONAL AIRPORT

11:57 HRS 30/03/82 PAGE 05

- The Findlay Irvine Ltd. ICELERT Mark IV system for airports is comparable in concept to the SSI scan system [4]. It was developed to warn personnel responsible for the condition of the runway that surface icing is likely to take place if the current trend of temperature and moisture persists. A probe assembly containing transducers for runway surface condition measurement is buried in the surface of the pavement. It measures surface moisture, surface temperature, the critical stage when moisture is about to start freezing (whether or not the moisture is water or dilute chemicals), and the presence of ice. This information is relayed by a remote processor unit to a central processor together with information on air temperature at a height of about 1.2 m (4 ft) above ground. Wind speed and direction measurements can also be included, but this is not normally considered necessary, since the chilling effect is measured by the probes. The central processor receives information by radio or by land-line and provides visual and printed summaries of the previous hour's trends; the trends are shown both numerically and graphically and, when critical, activate an audible warning signal. A typical printout is shown in Table 4B.

Each system is equipped with three sensors spread out along the main runway. Installed costs are reported to be $60-80 000 for each system. Operating regulations at the airport require runways to be inspected visually every four hours; if successful, the continuous monitoring of surface conditions would provide a safeguard against change occurring between the four-hour patrols and could lead to a relaxation of visual inspection. At this stage, however, it appears that the principal value of the system will be in providing an advance warning that the changing conditions warrant visual inspection; the need for this manual verification stems from the "blind" sensitivity of the probes which can, for instance, misinterpret conditions such as morning frost which are not hazardous to aircraft.

Of the two systems, the Findlay Irvine system, which was developed in Scotland, shows the most promise though problems have been experienced with the PYE radio transmission of data from the remote processor.

In contrast to the cautious approach at Toronto airport, it is understood that the SSI system is fully operational at Boston Airport and has replaced routine visual inspections of runway conditions (this has not been verified by direct contact with the Logan International Airport Authority).

2.2.5.2/ White-outs and Drifting Snow

A system capable of measuring the visibility of blowing snow has been successfully developed jointly by the US Department of Agriculture and the Wyoming State Highway Department [6, 7]. Particle size and frequency and wind speed are the main parameters affecting visibility in blowing snow. The system developed in Wyoming measures particle size and frequency using a photoelectric particle counter that produces a voltage pulse for each snow particle which passes through a 3 x 25 mm area. The sensor's pulse string is electronically-processed to give voltages proportional to 5-second averages of particle frequency and diameter. These voltages are combined with signals from an anemometer in an analog computer which estimates visual range. The estimates of visual range were calibrated by comparison with simultaneous observations by closed circuit television. This visual range monitoring system has proved to be a reliable indicator of visual range in blowing snow.

The system is able to distinguish between newly falling and blown surface snow, and the historic analysis of trends in snowfall and wind speed can be used to provide an advance warning of a potentially critical deterioration in visibility. The design of the snow particle counter is illustrated in Figure 3. Costs were reported in 1979 to be less than $1000 US each.

2.2.5.3/ Aqua-Planing

The risk of aqua-planing depends on the relationship between the friction of the road surface, vehicle speed, and the depth of water film, which in turn is dictated by the intensity of rain and the rate of surface runoff. Thus, for a given stretch of road, the risk of aqua-planing can be defined as a function of the intensity of rainfall. Rain intensity can be measured by placing automatic rain gauges on the road section; this will give a localized warning of danger.

Weather radar which can monitor the advance of heavy rain can make it practical to provide advance warning of treacherous conditions [8].

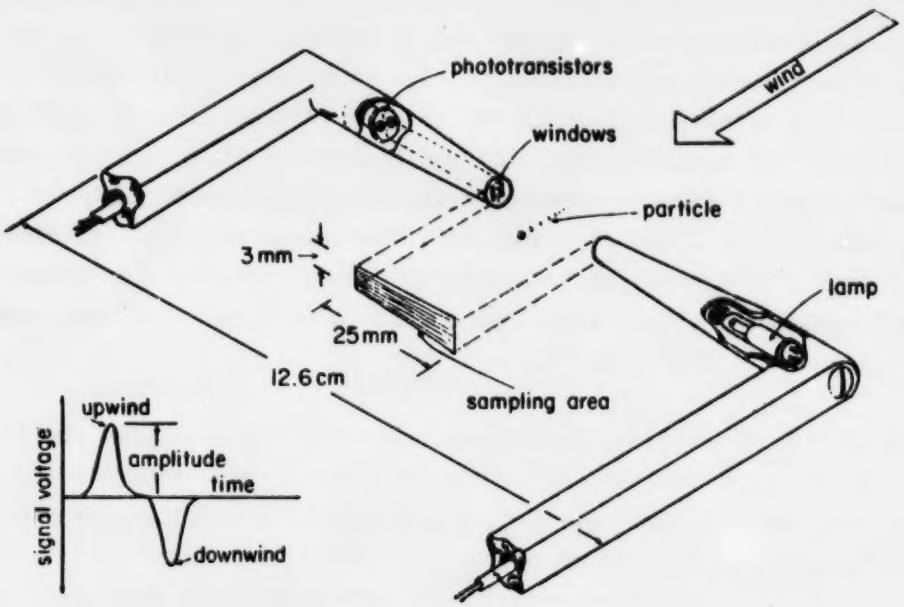


Figure 3/ Sensing Elements of the SPC Snow Particle Counter

2.2.5.4/ Fog

A number of methods have been developed for detecting the onset of poor visibility due to fog [1]. The most dangerous situations arise when poor visibility is confined to a small area with good visibility elsewhere. In these cases, the requirement is principally for en route warnings that local pockets of fog have formed.

Considerable work has been done in this field in the United Kingdom, but at this stage no detailed information has been obtained.

2.3/ Status Reporting

The feasibility of developing more dependable forecasts of micro weather appears to depend on the availability of an improved data base on local weather and surface conditions to supplement normal meteorological analyses at the regional level. This local data base can be developed by making better use of existing resources and by installing supplementary measuring devices at remote locations. The effective use of this localized data base will of course call for appropriate investigative and interpretive skills.

2.3.1/ Making Better Use of Existing Resources

The Ministry's normal maintenance activities offer a number of substantial opportunities to collect data on the current weather and surface conditions. These include:

- the installation of meteorological weather stations at each of the patrol yards (readings of air temperature, barometric pressure, humidity, wind direction and speed, and precipitation could be supplemented by key visual observations from personnel);

- visual observation of weather and road surface conditions at designated conditions;

- the fitting of skid resistance measuring devices to snowplows and sanding and salting equipment with the transmission of readings at designated intervals and/or locations.

2.3.2/ The Case for Remote Weather Stations

Away from the patrol yards, there is, however, a limit to the additional data that can be located by mobile patrols. For instance, the items of information needed to anticipate the onset of conditions favourable to freezing can only satisfactorily be measured by permanently installed monitoring stations. Similarly, to be useful, a continuous watch needs to be maintained over the possible deterioration in visibility due to blowing snow.

2.4/ The Transportation Nerve Centre (TRANCEN)

The successful monitoring and interpretation of regional and local weather information calls for a high degree of meteorological and analytical skills, as well as an understanding of local phenomena. For this reason, we believe that it would be most appropriate to centralize the reporting of information on weather and surface conditions in order to make the optimum use of the necessary professional resources. Possibly two or three centres may be warranted, two to cover Southern Ontario and possibly a third to cover the key areas of Northern Ontario.

2.4.1/ Concept

These central transportation nerve centres would be responsible for:

- the receipt and interpretation of data from patrol yards, patrolmen, snow clearance equipment, and remote weather stations;

- the monitoring of regional weather forecasts provided by Environment Canada to an agreed specification and format which would include special attention to the prospect of squalls from the lakes;

- the monitoring of low level weather radar reports on precipitation, where these are available from established agencies;

- the preparation of 24-hour and two-hour weather forecasts at the district level. These weather forecasts would take the form of alert bulletins to the patrol yards advising them of:
  - the need to put personnel on standby for snow removal during the next 24 hours,
  - the need to commence salting and/or sanding during the next two hours and the quantities that should be laid,
  - the need to watch out for the drifting of blowing snow at identified locations,
  - the likely need to institute road closures and/or advise traffic to reduce speed due to white-out conditions,
  - the need to warn traffic of fog banks,
  - the need to warn traffic of possible risks of aqua planing,
  - the end of the need for salting and sanding as temperatures move away from the critical freezing conditions.

In addition to relaying instructions to the patrol yards, the transportation nerve centre could also take over the responsibility for providing a public information service through:

- frequently updated, pre-recorded road condition reports,
- local radio and TV stations,
- other potential beneficiaries such as local airport operators and transit properties.

The concept of the transportation nerve centre is illustrated in Figure 4, which shows information being displayed on a series of monitors and printers.

2.4.2/ The Remote Weather Station

Conceptually, the remote weather station can be equipped to measure one or more atmospheric and surface conditions. For instance, at the patrol yards, there may be little point in installing visibility monitoring equipment. Normally, however, the remote weather station would be equipped to monitor:

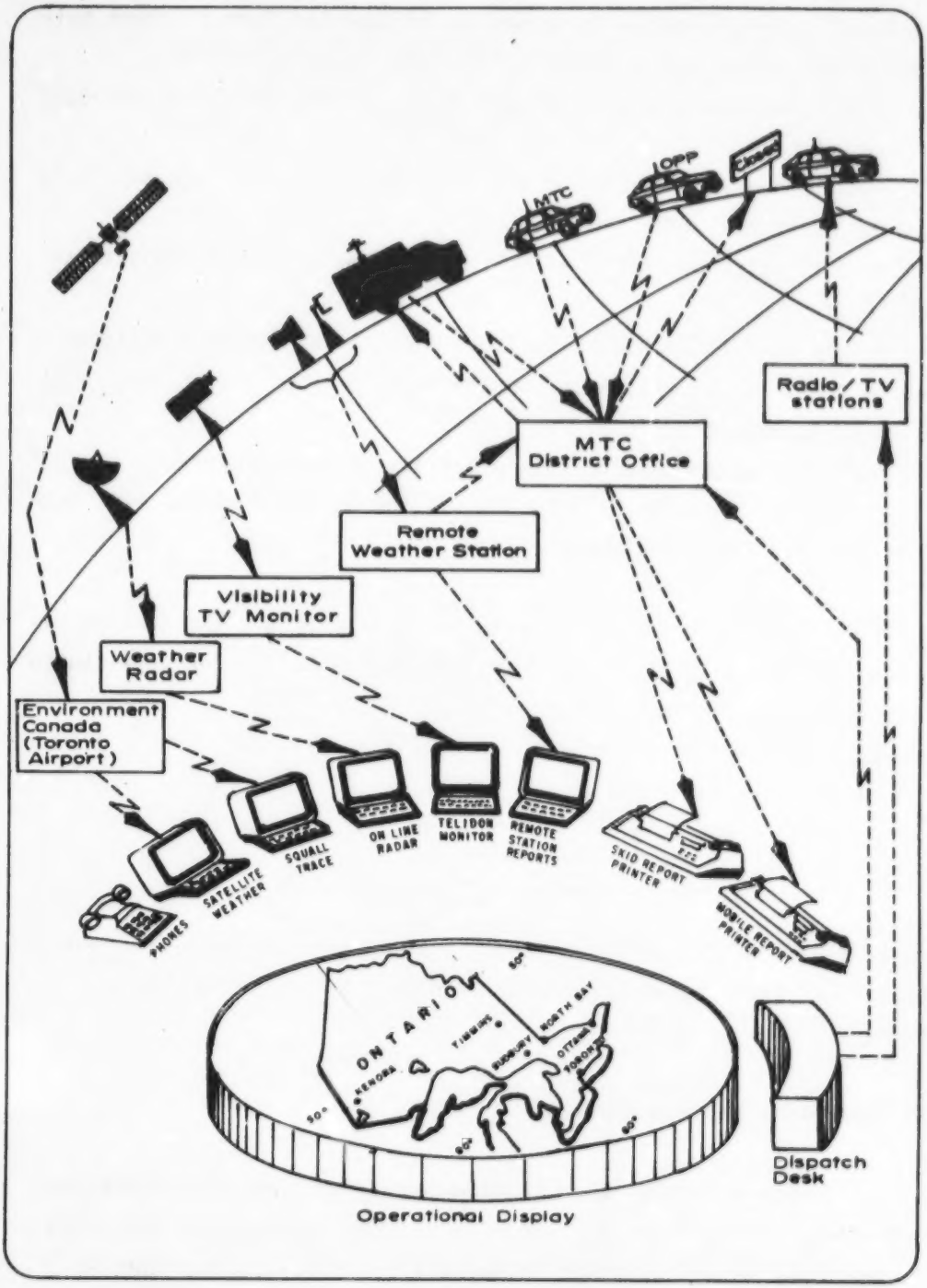


Figure 4/ The Transportation Nerve Centre

- the possibility of ice formation through surface and air moisture measurements,
- visibility in blowing snow through the measurement of particle size and wind velocity and direction,
- the rate of precipitation,
- fog formation in locations where this could be critical.

Readings from the remote station would normally be transmitted by radio to conveniently located relay stations (for instance at patrol yards) for onward transmission by land-line to the transportation nerve centre.

At selected stations, there may also be a case for incorporating an interval frame TV monitor to provide a visual measure of visibility to provide a backup system for white-out and fog detection.

2.4.3/ Estimated Cost of Remote Stations

An initial indication of the likely cost of establishing a remote weather station can be gained from published information on costs which indicate:

- a total cost of $60-80 000 for each of the ice alert systems under test at Toronto International Airport. This cost includes three sets of sensing devices, a remote processor, radio transmission of data, a central processing unit, a video display and a printer;

- snow particle counters costing $1000 US in 1979;

- instrumentation costs of $25 000 in 1979 to include all meteorological equipment and land-lines for transmission to a central processor. (This cost was quoted in a report on the development of an automatic system for observing, forecasting and warning of adverse road conditions due to bad weather in Finland. Operating costs were reported at approximately $7000 per year per installation.)

On the basis of this information, it seems likely that the equipping of a remote weather station could cost some $30-50 000, including a share of the cost of the central processing unit with its video display and printer.

2.4.4/ Locational Factors

A number of factors need to be taken into consideration in selecting suitable locations for remote weather stations. These include:

- known white-out locations such as Holland Marshes on Highway 400,
- access to land-line or feasibility for radio transmission of data,
- freedom from tampering.

2.4.5/ Visual Observations

The illustrative layout for the transportation nerve centre anticipates the receipt of information from patrolmen being transmitted over teleprinters or facsimile transmitters together with information on skid resistance.

2.4.6/ Other Data Sources

It is anticipated that existing arrangements for the receipt of forecasts from Environment Canada (see Section 2.1.4, Current Operating Practices) can be expanded to include more localized and/or more frequent information. Additionally, the illustrative layout for the transportation nerve centre anticipates that it will be possible to hook into a weather radar system.

2.4.7/ Staffing

The ability to interpret centralized information on weather and road conditions depends very much on the calibre of staff employed by the transportation nerve centre. It is anticipated that a minimum staff of two would be required round the clock -- a total crew of some 10 professional staff. Each team should include skills in meteorology and data analysis; it is understood that the Ontario Ministry of Natural Resources may be willing to make available meteorologists during the winter months. Also, it may be possible to amalgamate the MTC's Road Information Service into TRANCEN and the associated staff. The team should work very closely with the district supervisors, who should normally be responsible for transmitting instructions to patrol yards.

2.4.8/ Co-ordination

If, for practical or other reasons, more than one centre is needed to cover Ontario, neighbouring transportation nerve centres should share bordering information and should co-ordinate analyses and forecasts of weather conditions.

2.5/ Potential Benefits

The improved forecasting and subsequent detection of the duration of adverse weather conditions offers important benefits to MTC and to the public at large. Specific benefits include:

For MTC:

- Reducing the cost of keeping personnel on round-the-clock standby.
- Improved effectiveness in sanding and salting operations by being mobilized ahead of the commencement of adverse weather.
- Significant savings in the quantities of salt and sand used, as a result of monitoring the skid resistance of surfaces (assuming a suitable sideways-slip device can be developed).
- Reduced risk of roads being closed due to sudden snow drifting.

Additional illustration of the expected change in resource utilization is presented in Figure 5.

For Road Users:

- A lowering of accidents. Studies in Europe indicate that bad weather is a contributing factor to 20-25% of all accidents.
- Reduced exposure to sudden white-out conditions,
- Less corrosion as a result of reducing the unnecessary use of salt.

Adjacent Properties:

- Less environmental and ecological damage due to salt.

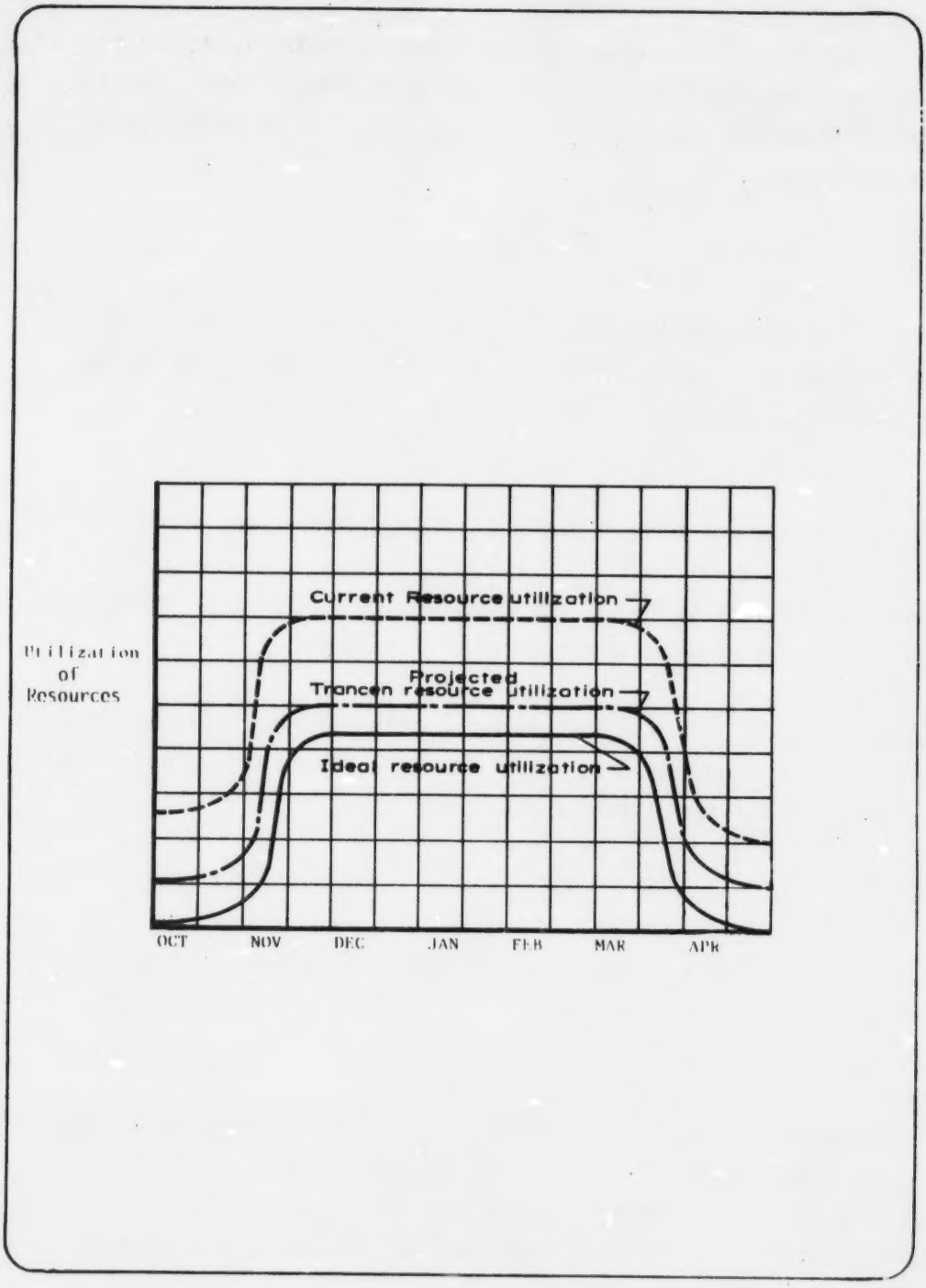


Figure 5/ Winter Resource Utilization

For Other Potential Beneficiaries including:

- Regional municipalities,
- Transit properties,
- Regional aerodromes.

No comprehensive information is available on the extent to which these benefits offset the cost of setting up a transportation nerve centre. Workers in Finland concluded that savings in the cost of accidents would offset about half the cost of equipping Finland's expressway system with remote weather stations. This led the Finns to conclude that the use of remote weather stations should be limited to accident black spots.

Austria appears to have taken a less cautious approach with a reported installation of 80 ice warning and 140 snow warning systems in use [10]. Researchers in Holland have concluded that ice warning systems can lead to the reduction of salting by 10 to 20%. With salt costing approximately $5 million a year in Ontario, a saving of $1 million would finance perhaps 50 remote weather stations. It is hoped that other savings could also be made, but it would be unrealistic to expect that these would add up to more than 10-15% of the total annual expenditure on winter maintenance -- in all, perhaps enough to finance the installation of some 200 remote weather stations.

Clearly, the siting and equipping of remote weather stations will have to be given careful consideration if the saving that can be gained from improved levels of confidence in 24-hour and short-term weather forecasts are not to be more than offset by the cost of developing those forecasts in the first place.

2.6/ Proposed Demonstration Project

It is clear that there is scope to improve the cost-effectiveness of winter maintenance operations, including substantial reductions in road patrol costs by making better use of existing sources of information on weather and road surface conditions, supplemented by the installation of remote weather monitoring stations. The advent of microprocessors has led to the development of a number of techniques for monitoring weather

in remote locations, and it seems clear that these techniques offer the opportunity to make significant improvements in the level of service offered to road users. What is not so clear, however, is the extent to which the cost of installing and operating these remote stations can be offset by saving expenditures on road maintenance which would otherwise take place. Nor is it clear how many of these remote stations are needed in order to provide a satisfactory level of coverage for forecasting purposes. It is also possible that the present design of the ice alert systems is too complex for general forecasting purposes, even at the local level.

For all of these reasons, we believe that it would be worthwhile running a demonstration project to determine, in the field, just how useful these latest developments in microprocessors can be in improving the level of service provided by MTC during the winter months.

2.6.1/ Coverage

For administrative convenience we would recommend focusing the demonstration project on a single district. The district should include a variety of topographical and highway conditions and be located in an area which is currently covered by weather radar.

2.6.2/ Equipment

The transportation nerve centre would be located in or adjacent to a district office, ideally in a location suitable for an expanded (province-wide?) service. Data linkages would be established with:

- Environment Canada for regional weather forecasts;
- area weather radar centre;
- selected (or possibly all) patrol yards with telecopier transmission of data read manually from meteorological observation posts established at each yard;

- information on surface, air and blowing snow conditions from at least five remote weather stations with data transmitted by radio or land-line to a central processor located in the transportation nerve centre;

- reports on road conditions at designated points, radioed in by patrol-men;

- skid resistance readings transmitted either orally or digitally by radio from suitably equipped snowplows and sanding/salting vehicles. This assumes that it will be practical to attach a sideways slip wheel to trucks without interfering with their operation.

2.6.3/ Staffing

The transportation nerve centre should be staffed round the clock by a team of two analysts, one of whom should be experienced in meteorology. In view of the current interest in the development of short-term localized weather forecasts, it is possible that Environment Canada would be willing to second meteorologists to MTC; also, there is the possibility of using Ontario Ministry of Natural Resources staff.

The team will be expected to work closely with the district supervisor who would normally be expected to assist in determining the reasonableness of proposed instructions and information.

Additional and independent resources will also be required to evaluate the results of the demonstration project.

2.6.4/ Criteria for Evaluation

The objective evaluation of the demonstration project will require a means to be established for comparing the action that has been taken with what would have occurred had things been continued to be done as they were in the past. The setting up of this comparative basis for evaluation may in itself dictate that one district is more suited than another for the demonstration project, especially if it is possible to find two closely paralleled roads which are serviced by different districts.

Key criteria for evaluating the potential advantages of a transportation nerve centre and supporting remote weather stations include:

- reductions in the overall cost, labour and supplies, calculated from the advance warning that would have been given (for the purposes of the demonstration project, it is not expected that staff will actually be released from standby);

- the number of occasions in which 24-hour forecasts of no change would have been wrong;

- the number of occasions on which insufficient notice was given to enable equipment to be fully mobilized before the advent of a snowstorm or freezing surface conditions;

- the number of occasions in which white-outs occurred and were detected by remote weather stations;

- the overall change in reported accidents.

A separate and special assessment will also be made of the dependability that could be attached to extrapolations of change in surface conditions which could lead to the formation of ice and the extent of which less complex apparatus could have produced similarly satisfactory results.

2.6.5/ Estimated Cost

It is estimated that the cost of equipping the demonstration project could amount to some $400 000. This estimate would provide for:

- a minimum of five remote weather stations equipped to provide ice, fog and white-out alerts, together with the central processors (say $200 000);

- telecopier links with ten patrol yards (say $20 000);

- the equipping of up to ten trucks with sideways slip wheels, radio transmitters and a central receiver (say $20 000);

- the furnishing of a transportation nerve centre (say $10 000);
- the provision of remote meteorological stations at each of ten patrol yards (say $15 000);
- the installation of a remote terminal for the weather radar and the associated rental cost (say $5000);
- the installation of a data transmission link between Environment Canada and the transportation nerve centre (say $5000);
- on-site review of comparable projects including Wyoming, Finland, Austria, Holland, and Britain (say $10 000).

Other costs for the demonstration project would include the cost of consulting services estimated at:

- the design of the demonstration project (say $35 000);
- the initiating and evaluating of the demonstration project (say $40 000 a year); and
- the opportunity cost of staff assigned to this project.

Taken individually, the foregoing estimates of cost are subject to significant qualification. However, taken together, it is considered they provide a reasonable estimate of the total budget which should be established to cover the cost of the demonstration project over and above the cost of staffing the transportation nerve centre with MTC and possibly Environment Canada personnel.

2.6.6/ Timing

We believe that it will be necessary to run the demonstration project for two successive winters in order to obtain a reasonable understanding of the benefits offered by the systems under test. If a decision to proceed is made by the end of April, it should be possible to start the demonstration the following winter. This would provide sufficient time to undertake the following activities:

Activity	Timing
Verify the efficiency of sensing equipment through face-to-face discussions with operating agencies.	April/May
Finalize scope and prepare detailed work plan for project. Confirm budget.	May
Select most suitable district and patrol yards and associated test sites.	June
Prepare outline specifications for procurement of equipment.	June/July
Place orders for sensing equipment and other requirements.	August
Negotiate linkages with Environment Canada, with a local weather radar facility and as necessary with Bell Canada and other agencies.	August/September
Negotiate staff for centre.	September
Prepare Transportation Nerve Centre for installation of equipment.	October
Install and test equipment.	October/November
Commence trials.	December

3/ HAND-HELD RECORDERS

3.1/ Introduction

The Phase I review of microprocessor applications noted the development of a number of systems to facilitate the electronic recording and analysis of field observations. Field observations are keyed directly into the memory of pre-programmed hand-held recorders; stored information is transferred directly to mainframe computer for analysis and interpretation, if necessary, using a telephone coupler. The system reduces scope for errors in the initial recording of data and eliminates subsequent coding and punching. Originally developed to eliminate sources of error in the collection, transcription and entry of survey data, the systems are equally applicable to a wide range of data collection and analysis requirements, including:

- stock taking and inventory replenishment;
- highway condition surveys and maintenance programs;
- licence plate O-D surveys;
- traffic counts.

The hand-held recorders can be custom-programmed to instruct the operator on the sequence of information required; the task of recording information can be simplified by purpose-built key descriptions.

3.2/ Typical Systems

Several systems are currently on the market, including:

- a hand-held micro-computer developed by Data Recognition in conjunction with the Transportation and Road Research Laboratory in England,
- the Hewlett-Packard HP-41C/CV calculator system,
- the Norman Wade 101 Alpha Electronic Field Book,
- the Keuffel & Esser standard field computer which can be custom-programmed.

Literature describing these systems was reviewed by the Steering Committee.

3.3/ Estimated Cost

Indicative estimates of cost have been obtained for each of these representative systems. These costs are summarized in Table 5, together with comments on the current flexibility of the systems.

Table 5/ Summary of Hand-Held Systems

SYSTEM (MANUFACTURER)	COMPONENTS	INDICATIVE COST	COMMENTS
Dataport 5 (Data Recognition, Unit 18, Suttons Industrial Park, Earley, Reading, Berkshire R6G 1AZ)	Hand-held microcomputers (Program up to 18K bytes; Memory up to 96K) Portable acoustic coupler	$ 4000 $ 1000	Initially programmed to prompt field inspectors through the systematic documentation of road conditions. Interchangeable programs are being developed for other purposes such as traffic counts.
HP-41CV (Hewlett-Packard Ltd. 6877 Goreway Drive, Mississauga, Ont. L4V 1M8)	Hand-held calculator (Memory 6.5K; cassette storage adds 131K) Cassette storage (Interfaces with HP-80 microcomputer)	$ 550 $ 935	Wide range of application packs are available; also can be custom-programmed. Limited memory could be restrictive where use in conjunction with cassette storage would be cumbersome.
101 Alpha Norand (Norman Wade Co. Ltd. 75 Milner Ave., Scarborough, Ont. M1S 3R7)	Hand-held electronic field book (Memory up to 64K)	$ 5000	Pre-programmed prompts; requires new micro-processors for each application. (Currently only developed for surveying and stock control)
Vectron Field Computer (Keuffel & Esser 1630 50th Avenue Lachine, P.Q. H8T 2V5)	Hand-held electronic field book (Memory up to 4K) Standard Coupler	$ 8000 $ 750	Currently only available for survey work but can be custom-programmed at extra cost.

4/ REFERENCES

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c) "The Development of a Microwave Radiometer for Use as a Highway Ice Detector," U.S. Transportation Research Board Workshop, April 24/25, 1980.

d) "Automatic Weather Station with Speech Output," Freden, S., National Swedish Road Admin., 1979.

e) "Automatic Fog Alert System Protects Busy Highway," Rural and Urban Roads, VII, N.5., May 1973.

f) "Automatically Speaking Weather Station," Gilen, C., National Swedish Road and Traffic Inst., 1978.

g) "Installation of Fog Guidance Lights on Afton Mountain," Virginia Highway and Transportation Research Council, August, 1976.

h) "Automatic Controls for Street Lighting," Woolnough, A.F., England Illumination Engineering Society, Lighting and Control, V64, N10, Nov. 1972.

i) "Electric Services and Lighting," Caradus, W.G., New Zealand Engineering, August 1975.

j) "Sensor Applications in Road Tunnels," Fudger, G., London, Sensors in Highway and Civil Engineering, Institution of Civil Engineers, 1981.

k) "The Measurement of Fog on Motorways," Douglas, H.A., Jeffrey, D.J., Jezzard, F., Meteorological Magazine, V107, 1978.

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[5] "Scan System 16 -- Operators Manual," brochure produced by SSI Surface Systems Inc.

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[7] Visibility in Blowing Snow and Applications in Traffic Operations," Tabler, R.D., Rocky Mountain Forest and Range Experimental Station, Proceedings of 2nd International Symposium on Snow Removal and Ice Control Research, 1978.

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[9] "A New Automated System for Forecasting Precipitation Type," Bocchier, J.R., Techniques Development Laboratory, National Weather Service, Silver Spring, MA.

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Appendix A/ Interviews Conducted

As outlined in the workplan and the terms of reference, HWS Controls conducted fact-finding interviews with key MTC staff experienced in highway construction and maintenance operations. In addition, further interviews were carried out in both Ontario and Europe, the former to obtain broader knowledge in particular areas and the latter as part of the European data gathering exercise. The list of interviews follows:

MTC Personnel Interviewed

J.H. Blaine*	Head, Maintenance Management Section, HO
D.R. Brohm*	Manager, Maintenance Operations Office, HO
Z. Byblow*	Head, Surveys & Plans Section, Central Region
E.R. Case*	Manager, Control Systems Research, R&D Branch, HO
S. Cohen et al	Maintenance Methods, Maintenance Operations Office, HO
F. Jung	Project Engineer, Materials & Environment Research, HO
J. Kernaghan*	Manager, Maintenance Services Office, HO
R.P. Northwood*	Area Construction Engineer, Central Region
W.A. Phang	Manager, Pavement Research, R&D Branch, HO
J.K. Robinson*	District Maintenance Engineer, Toronto
A. Rutka	Manager, Materials & Environ. Research, R&D Branch, HO
E.F. Schroeder*	Project Leader, Control Systems Research, R&D Branch
G.M. Sinclair*	Regional Maintenance Engineer, Central Region
J.G. Slubicki	Manager, Equipment Office, HO
A.G. Stermac	Manager, Engineering Materials Office, HO

The interviews with the persons listed above included questions about current developments within the MTC and other foreseeable applications. Those applications currently under development or being considered by MTC include:

- Road condition detection
- Highway lighting management
- In-motion weigh scales
- Evenness of road wear/ride comfort

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*Steering Committee members who participated in Phase 1 and/or Phase 2 of the Project.

The applications that MTC personnel brought forth in the interview program as warranting investigation included:

- Weather condition detection
- Automatic control of shoulder graders/snowploughts
- Automation of road patrol maintenance estimates
- Use of robots in construction activities
- Upgrading of current layout surveying techniques
- Automatic control of aggregate grading
- Automatic control of asphalt plants
- Automatic control of seeding and mulching operations
- Automation of traffic counting and classification
- Automation of highway grade measuring
- Shortening of highway photolog cycle
- Improvements in zone striping quality

Other Interviews:

- J.C. Howarth, President
  Chevron Asphalt

- P. Belcher
  The Ministry of Transport, U.K.

- Messrs. Thompson, Gudesell and Edwards
  The Transport and Road Research Laboratory, U.K.

- M. Parey, Adjoint au Directeur
  Laboratories des Ponts et Chaussees, France

- H. Vooijs, Research Engineer
  Rijkswegenbouw Laboratorium, The Netherlands.

Additionally, a number of discussions were held with people attending a conference on Sensors in Highway and Civil Engineering which was held in London, England, in February, 1981.

Appendix B/ Classification of Potential Applications

	Codes	Application Label	Information Sources *
Highway Construction Processes			
Pavement Materials	C01	Paving	B1
Aggregate Materials	C02	Aggre.	B2,B3,B4,B5
Construction Equipment	C03	Shoulders	B6,B7
Formation Levels	C04	Lasers	B8
Surveying	C05	Inertial	B9
	C06	EDM	B10
Structures	C07	Pile	B11
Concrete	C08	Recipe	B12
Asphalt	C09	Loops	B13
	C10	T-Test	B14
	C11	Recipe	B15
	C12	Paving	B16
Miscellaneous	C13	Gamma	B17
Applications not tabulated			B18,B19,B20
Highway Operations Processes			
Weather Condition	001,008	Weather	1(d,e,f,g,j,k)
Road Surface Condition	002	Road	1(a,b,c)
Lighting Management	003	Remotelite	1(h,i)
	010	Centlite	B26
Weight Monitoring	004,006, 007	Scales	B21,B22,B24,B25
Highway Traffic Measurement	005	Veh. Class	B23
Roadside Equipment	009	Roadside	1(j)
Lane Markings	011,012	Lane Mark	B27, B28
Applications not tabulated			B29,B30,B31
Highway Maintenance Processes			
Highway Photologging	M01,M05	Photolog	B32,B37
Robots	M02	Robot	B33
Road Condition Inventory	M03,M04	Hand-Held	B34,B35,B36
Road Surface Monitoring	M06,M07, M08	Profile	B38,B39,B40
	M09	Load Cell	B41
Applications not tabulated			B42,B43,B44

*B-prefixed "source" numbers are in Appendix C, Bibliography.
Unprefixed numbers are in Section 4, References.

Appendix C/ Bibliography

Highway Construction Application Area

[1] "Research on the Automatic Control of Manufacture of Pavement Materials," Kirkham, R.H.H., Mathews, D.H., Gt Brit, Min Transp, Road Res Lab, RRL Rep LR 401, 1971. (C01 Paving)

[2] "Process Control for Aggregate Production and Use;" Forster, S.W., Public Roads, US Dept of Transp, Sept 1980. (C02 Aggre.)

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[5] "Process Quality Control in the Crushed-Stone Industry," Nichols, F.P. Jr, US Transp Res Brd, Transp Res Rec N691, 1978, pp 4-7. (C02 Aggre.)

[6] "Automatic Controls for Construction Equipment," World Construction, V24, N2, Feb 1971, pp 38-40. (C03 Shoulders)

[7] "Optical Control of Earthworks Machinery," Kardaev, M.A., Malyar, V.S., Mechanizatzya Stroitel'stva, N1, pp 18-19. (C03 Shoulders)

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Highway Operations Area

(Primary report references are listed in Section 4)

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[33] "Robots Becoming Kings of the Factory Floor," Lancashire, D., The Globe and Mail, Mar 4 1981, p 7. (M02 Robot)

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